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ABSTRACT

The termination depth of bored cast in situ piles poses serious problem to the field engineers particularly on weak weathered rock, stiff clays and dense sands. Some sort of decision making tool is available for driven piles in the form of driving formulae. The first part of paper deals with a simple method based on penetration resistance to the advancement of bore and its relation with end bearing and frictional resistance offered by formation.

The second and third parts of paper deal with a newly conceived dynamic method for ascertaining the safe load on pile and its comparison with the safe load value derived from penetration resistance actually observed. The dynamic test proposed is simpler, quicker cost effective and shall be an excellent quality assurance tool for the bored cast-in-situ piles.

INTRODUCTION

Piles are designed using shear parameters of rock and soil obtained from laboratory testing. The validity of design is checked on subjecting the piles to the static load test. The driven piles criteria outlined by pile driving formulae provide a useful guiding tool for termination of piles. During the construction of bored cast-in-situ piles, in the absence of such method the field engineers always are at loss and are not so sure whether pile can be safely terminated. The method outlined below shall serve as quality control tool for termination of bored cast-in-situ piles. The method is based on well known principle of equivalence of energy. Use of Prof. Mayerhoff's analysis relating SPT to load carrying capacity is extended to get the correlation between chiseling energy and load carrying capacity of bored cast-in situ piles.

In the second half of the paper the newly conceived method of dynamic testing of pile using infrared producing unit is described at length followed by a discussion on the comparison of safe load values obtained by penetration resistance method and dynamic tests on the piles. In the end the finding are summarized in the form of conclusions.

METHOD OF ESTIMATION OF RESISTANCE

Since the early days of driven piles the termination of criteria based on "Sets" observed are followed. Various formulas are available. The Indian Standard Code 2911 Part I covering driven piles outlines such formula. The principle followed is recording the penetration for blows of the hammer and on that basis having obtained the desired set i.e. average penetration of standard numbers of blows of hammer the ultimate capacity the pile is worked out and then with suitable factor of safety, the safe capacity is arrived.

The similarity in relating chiseling energy / penetration energy to termination can be seen in the method followed of driven piles and 'SPT' tests. In fact the standard penetration test as the name indicates measures number of blows for 30 cm penetration and as such gives resistance to penetration of a given formation standard energy. It is also well known that N = 50 is deemed as commencement of hard strata. (Meaning thereby the strata is now approaching stage of weathered rock). If one calculates the energy for N= 50 in the units of Tm/m²/cm as is done for chiseling resistance we get,

$$\mathbf{E} = \frac{W \times h}{A} \times \frac{N}{S} \qquad (1)$$

$= 36$ tm/m^2/cm

Where,

E = Penetration Resistance in tm/m^2/cm

W = Weight of hammer = 63 kg

A = Area of Split Spoon Sampler = 20 cm^2 (Approx.)

N = Number of blows = 50

S = Penetration of sample = 30 cm

h = Hammer drop distance = 75 cm

The use of standard penetration tests in estimation the pile capacities is well documented. Prof. Mayerhoff has suggested following relation to work out the pile capacity from 'SPT' for driven piles. The relation reads (1956 A.S.C.E.)

$$Q_{ult} = 40 \, N \, A_p + \frac{\overline{N}}{5} A_S \; - \text{(In Tonnes)} \qquad (2)$$

A_P = Base area in m^2 N = 'SPT' at base
N = Average 'N' on shaft portion offering frictional resistance.
As = Surface area of shaft in m^2

The factor of safety recommended by Prof. Mayerhoff is 'Four' for driven piles. Recognizing the difference in method of boring namely 'displacement and replacement' as it is often described, it is suggested to take the factor of safety equal to 6 instead of 4 suggested by Prof. Mayerhoff for driven piles. Further the settlement allowed by Prof. Mayerhoff is of the order of 20 mm while the present Indian Standard Code suggests value of 12 mm at 1.5 times the working load. Taking into account these two aspects it is proposed to adopt a factory safety of 'ten' for end bearing resistance while factor of safety for frictional resistance is 'six'. The relation for safe capacity of bored cast-in-situ piles therefore works out as under.

$$\text{Pile capacity} = 4 \, N \times A_P + \frac{N}{20} A_S \text{ (In Tonnes)} \qquad (3)$$

Or simply 4 N T/ m^2 as S.B.C. or end bearing resistance of formation for bored cast-in-situ piles.

The observed chiseling / penetration energy during the execution of bored cast-in-situ piles can then be compared with the penetration energy for N = 50 to obtain projected N value of the strata. It is of an interest to know that the method of energy application during execution the conventional bored cast-in-situ piles is quite superior to that of SPT energy and as such the error as a result of comparing two different type of energy application is on conservative type.

The estimate of 'N' value of the formation can be made from chiseling / penetration energy. While developing the bore for a pile the energy required to advance the pile bore of given cross section by unit penetration can be calculated resorting to the following relation

$$E = \frac{W \times H \times N}{A \times S} \qquad (4)$$

W = Weight of Chisel / boring tool,
H = Fall of Chisell in metre
N = No. of Blows
A = Cross Sectional Area of pile
S = Penetration in cm
E = Penetration resistance in Tm/m^2/cm

It is noted that 36 TM / m^2 / cm energy correspondence to N = 50 blows. It means that projected SPT value corresponding to obtained penetration energy can be worked out and from that the SBC of the formation can be worked out

S.B.C. in T / m^2 = 5 to 6 times Chiseling / Penetration energy x Tm / m^2 / cm

It is observed that in most of cases of weathered rock in brecciate and Tuffecious formation chiseling / penetration energy of the order of 60 to 75 TM / m^2 / cm shall be available right from the commencement. It means that the strata is capable of 300 t/ m^2 to 375 t /m^2 as safe load carrying capacity as end bearing resistance. To take full advantage of the concrete capacity of pile the pile may be socketed so as to avail additional resistance in the form of socket friction.

As regards the socket friction in weathered rocks it may be taken to be equal to 5 % of SBC obtained from chiseling resistance.

METHOD OF AUGER PILING

The principle of energy equivalence can be extended to auger piling. For the auger piling the rotary method is applied. The torque is generated and the blades of the auger are rotated to cut the formations so as to develop the bore. The imparting energy is given by the relation.

$$\text{HP of the engine} = \frac{2 \pi \, NT}{4.5} \qquad (5)$$

Where HP is horsepower

N = Revaluation per minute   T = Torque in TM

The cutting action of formation takes place under the torque energy and the relation stated below gives the auguring resistance in TM / m^2 / cm

$$E = \frac{2\pi \; NTt}{A \times S} \qquad (6)$$

E= Auger Penetration resistance in $Tm/m^2/cm$
A = Cross sectional area of pile in m^2
S = Penetration in cm.
T = Time of penetration in minutes

On availing the penetration energy in TM / m^2 / cm the relation mentioned earlier namely (5 x auguring energy in TM / m / cm) gives the SBC in t / m^2. Similarly the socket friction is given by following relation.

It is suggested to work socket friction in weathered rocks from following relation

F = 0.25 x E
Where F is socket friction in t/m^2

In brief the table below gives the guidelines for the engineers associated in design and construction of bored cast-in-situ piles.

Table No. 1 Guidelines for deciding termination of piles

Chiseling Energy or Auguring Energy / Penetration Energy $Tm/m^2/cm$	Safe End Bearing Resistance (S. B. C.) T/m^2	SOCKET friction T/m2
60 $Tm/m^2/cm$	300 T / m^2 to 360 T / m^2	15 T/m^2 to 18 T/m^2
75 $Tm/m^2/cm$	375 T / m^2 to 450 T / m^2	18.5 t/m2 to 22.5 t/m^2
100 $Tm/m^2/cm$	500 T / m^2 to 600 T/ m^2	25 t/m2 to 30 T/m^2

NEW METHOD OF DYNAMIC TESTING OF PILES

The large diameter piles have become a common feature of present day engineering activity. The conduct for the static load test either by Kent ledge or anchors is a time consuming and the conduct of the test obstructs the piling activity for an appreciable period. Infact at times even the minimum percentage recommended by the standard are not implemented.

The piles being underground activity; that also quite deep in nature, the quality assurance of workmanship and adequacy of the founding strata calls for more rigorous testing programme. For superstructures the new methods like ultrasonic testing, core testing etc. have provided number of ways for verifying the quality of the work. However for underground strata the available methods are limited.

The recent advances in the field of piling engineering related to dynamic behavior of the piles has led to the development of dynamic methods of testing the piles. However the equipments used are not only costly but one has to depend on the software results depriving the user of verification of refusal. It is in this background the authors have conceived a simple dynamic test based on the laws governing the dynamic impact of elastic bodies. It is based on using available dynamic formulae which equates the energy of hammer blow to the work done in overcoming the resistance of ground to penetration of pile. Allowance is made for losses of energy due to the elastic contractions of the pile, cap and subsoil as well as the losses caused by the inertia of the pile.

METHODOLOGY

The tests are carried out using an infra red producing unit 'NOPTEL' manufactured in Finland. However any similar equipment can be used. The methodology of test is based on a large weight giving the dynamic impact to the elastic body. It equates the energy of hammer blow to work done in overcoming the resistance of the founding strata to the penetration of the ordinary cast in situ piles as well as grouted micro piles. Allowance is made for loses of energy due to the elastic compression of the pile, and subsoil as well as losses caused by the impact of the pile. The modified Hiley's formulae given in the Indian Standard Code 2911 part – 1, Section I is used in estimating the ultimate driving resistance in tones. Applying the factor of safety as outlined in the code the safe load on pile can be worked out.

The instantaneous displacements including rebounds of the pile are precisely recorded in automatic data acquisition system. This is done for several cycles and then using formulae as accepted in Indian Standard Code 2911 the safe loading capacity is calculated. The opto electronic instrument is used for position sensitive measurement by non contact periodic measurement using instrument placed away from the vibrations due to impact load. The system is based on combined light emitting diode transmitters and a position sensitive detector. The transmitter and receiver are installed so that the infrared light beam forms a reference line from transmitter, receiver to the prism group reflectors. The reflected light is received and recorded upto 100 times per second. Using the energy transmitted to the pile and accounting for temporary compression of pile, ground and dolly occurring during the impact loading the ultimate driving resistance is calculated. Applying the factor of safety the safe load for the pile is calculated.

ADVANTAGES

1. Compared to the static test this method is less time consuming and hindrance to work in the adjoining area is much less.
2. The transmition of energy from drop hammer to pile is calculated taking in to account the relative masses of pile and drop hammer and coefficient of restitution of bodies under impact.
3. The observations of displacement are up to 0.01 mm. and such recording up to 100 per seconds can be taken and complete displacement profile is obtained.
4. The non contact method of recording eliminates effect of vibration due to machines.
5. The method follows the formula given in the Indian code and calculation methods.
6. The cost of test is low.
7. The formulae used for calculation gives best correlation among the various dynamic formulae in use for reinforced concrete piles.
8. The impact loading arrangement is such that pile testing can be conducted without damaging the head or cutting the reinforcement bars.

TEST RESULTS

Table 2A. Piles Founded On Tufficious Breccia

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes	Safe Load Structural Capacity in Tonnes	Design Load
1	63.36	*N. A.	105	55
2	256	270	160	120
3	76.8	*N. A..	74.1	55
4	14.7	*N. A.	74.1	55
5	48.2	*N. A.	74.1	55
6	46	45	40.0	40
7	262	242	313	170
8	329	223	293	175
9	193	145	100	80

Table 2B. Piles Founded On Tufficious Breccia

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes	Safe Load Structural Capacity in Tonnes	Design Load
10	208	252	160	120
11	454	440	280	200
12	276.81	180.00	205.36	130
13	283.85	225.36	205.36	130
14	498.92	894.40	339.51	220
15	322.01	637.33	217.29	130

*N. A. = Not Available

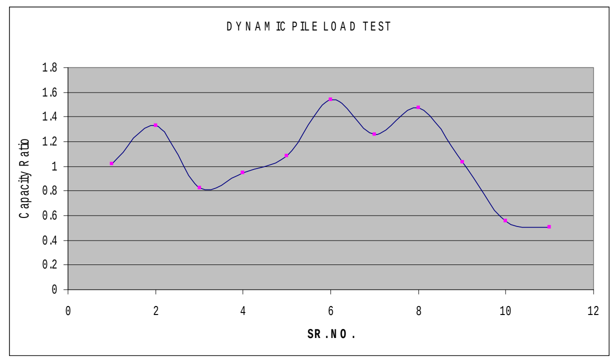

Fig. No. 1 Ratio of safe test capacity & safe capacity from penetration resistance.

Table 3A. Piles Founded On Weathered Basalt

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes	Safe Load Structural Capacity in Tonnes	Design Load
1	176	155	140	90
2	220	-	171	130
3	163	150	164	130
4	178	167	164	130
5	145	140	115	85
6	94	90	84	55
7	145	155	115	85
8	78.42	104.76	98.27	50
9	151.94	67.79	98.27	50
10	76.84	55.09	98.27	50
11	217.78	129.20	98.27	50

Table 3B. Piles Founded On Weathered Basalt

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes	Safe Load Structural Capacity in Tonnes	Design Load
12	100.78	98.80	98.27	50
13	74.34	83.60	98.27	50
14	159.78	103.11	98.27	50
15	79.24	178.79	98.27	50
16	236.21	132.00	205.36	130
17	106.01	88.00	153.55	90
18	115.25	160.00	153.55	90
19	133.75	116.00	203.36	130
20	258.34	231.00	153.55	90
21	351.91	448.80	153.55	90
22	289.15	221.00	205.36	130
23	203.87	204.00	205.36	130
24	226.96	229.17	203.36	130
25	133.19	111.30	192.47	115
26	108.94	148.40	140.66	90
27	191.12	178.00	92.54	60
28	184.74	172.44	92.54	60
29	167.47	169.10	139.23	90
30	200.5	169.10	139.23	90
31	284.42	158.86	112.56	75
32	144.49	101.36	112.56	75

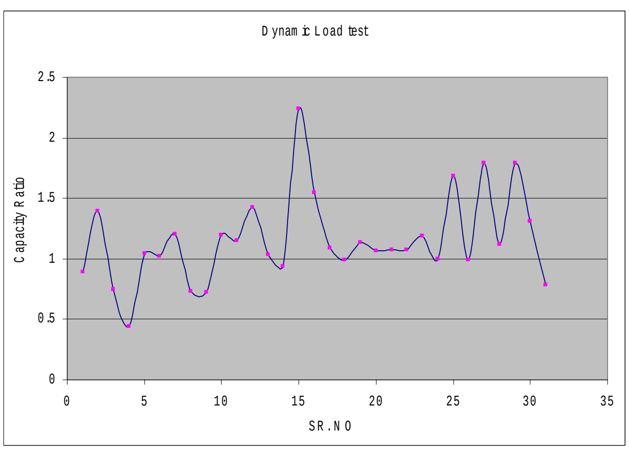

Fig No. 2 Ratio of safe test capacity & safe capacity from penetration resistance.

DISCUSSION ON TEST RESULTS AND CONCLUSION

A glance at the test results and the curves relating safe load by dynamic test v/s safe load by penetration resistance show that there is fairly good agreement between the two values. It can also be seen that the variation between the two sets of values is between 20 to 40 % in majority of the cases.

The real difficulty in bore cast in situ piles is the termination of piles on a strata contemplated by designer as per the design assumptions. The penetration resistance method shall help the field engineers to terminate the piles on the adequate strata using principles outlined and after a curing period the piles can be tested by dynamic test for confirmation purpose. This will also help in modifying the socket length etc.

The piles resting on Tufficious Brecciatic formation are showing a closer agreement between the two results. The dynamic test results shall be treated as closer to reality than the penetration method as penetration resistance data collected from the site at times suffers from approximation. With proper care in recording the data of penetration resistance a better match between the two results can be obtained.

The other important aspect, which is noted from the test results, is the fact is conservative approach of the designers in working out the pile capacity. It is noted that at many a times the piles can take nearly 40 to 60 % more load then the designer has recommended probably because of lack of confirmatory evidence.

The resort to penetration resistance method for termination of piles and confirmation the same by the dynamic test shall be very useful quality control tool for bore cast in situ piles. With more and more data available the gap between the design load and actual load piles can take shall reduce.

REFERENCES

Indian Standard Code of Practice for Design & Construction of Pile Foundation IS 2911 [Part 1 / Section 1] [1991] Dynamic Pile Formulae Appendix B

Mayerhoff G. G. [1956] "Penetration Test and Bearing Capacity of Cohesionless Soils', A.S.C.E. Proceeding Paper No. 866